Seasonal and diurnal patterns of water quality in created riparian wetlands

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Abstract

Chemical data was collected over an eight-day period in late October and early November 2002 in the two experimental wetland basins. Nitrate concentration increased significantly from the inflow to outflow in both wetlands (Inflow: 2.32±0.55 mgL^{-1}, W1 outflow: 4.14± 0.94 mgL^{-1}; W2 outflow: 4.17± 0.42 mgL^{-1}). Reactive phosphate concentration also increased significantly from inflow to outflows (Inflow: 1.40±0.21 mgL^{-1}; W1 outflow: 2.01± 0.35 mgL^{-1}; W2 outflow: 1.85± 0.19 mgL^{-1}). Other water quality parameters measured included conductivity, redox potential, pH, temperature, and dissolved oxygen. No significant differences were found between W1 and W2 for any of these parameters. Dissolved oxygen decreased longitudinally in both basins (Inflow: 8.40±0.25 mg L^{-1}; W1 outflow: 6.36±0.79 mg L^{-1}; W2 outflow: 6.40±0.75 mg L^{-1}). Temperature also decreased longitudinally (Inflow: 12.2±0.4 ˚C; W1: 10.4±0.6 ˚C; W2:10.6±0.7 ˚C). Dissolved oxygen concentrations and pH at each outflow displayed clear diurnal patterns. Average diurnal rates of change in dissolved oxygen were significantly higher in July 2002 compared to October 2002 (W1: 0.92±0.17 mgL^{-1}hr^{-1} in July and 0.27±0.10 mgL^{-1}hr^{-1} in October; W2: 0.64±0.11 mgL^{-1}hr^{-1} in July and 0.18±0.03 mgL^{-1}hr^{-1} in October). In October and July, rates of change were higher at both outflows compared to the inflow.

Introduction

Previous water quality research at the ORWRP "kidneys" has indicated that the wetlands generally act as sinks for nutrients and suspended solids. Retention of soluble reactive phosphorus has been particularly high, showing 60% retention or greater from 1995 to 2001. Phosphorus retention in 1996 was over 80% for each wetland basin. Nitrate-nitrogen retention has ranged from 47.5% in 1994 to 17.5% in 1997. Most recently, in 2001, nitrate-nitrogen retention was 33% in Wetland 1 and 44% in Wetland 2. Suspended solids have generally decreased in both wetlands from the inflow to outflows, following the pattern of phosphorus retention. However in recent years (2000-2001) the retention rate has decreased due to the lack of macrophyte cover and frequent re-suspension of sediments (Mitsch et al., 2000; Mitsch and Zhang, 2001). Measurements of nutrients, turbidity, DO, temperature, pH, and conductivity have not shown visible trends.

Significant differences between W1 and W2 have been found for several chemical parameters. The most dramatic difference occurred in 1995, when W1 retained 4% more total phosphorus than W2 (Nairn and Mitsch, 2000). Significant differences in temperature, turbidity, DO, pH, and conductivity were also found in 1999 and 2000 (Mitsch et al., 2000). In 2001, only conductivity, pH, and total phosphorus were significantly different between the two wetlands (Mitsch and Zhang, 2001).

This study focuses on many of the same water quality parameters studied previously: nitrate-nitrogen, reactive phosphorus, DO, pH, redox potential, conductivity, and temperature. Diurnal trends of dissolved oxygen and pH are examined, as well as longitudinal trends from inflow to outflow of both wetlands. The two wetlands are also compared to each other. Data collected during late fall, a time of low productivity, is compared to data collected in July, and seasonal patterns are analyzed. Some of these trends are compared to previous data described above.

Methods

Sampling and field analysis

Sampling sites for this study were evenly spaced throughout each wetland (Figure 1). Because both wetlands receive their water from an identical source, inflow samples taken from W1 are used for analysis of both wetlands. It is generally assumed that the chemical parameters of both inflows are identical (Mitsch et al., 2000).

Dissolved oxygen (DO), temperature, pH, specific conductivity (SpC), and redox potential were measured at all sites, in addition to one site at the river intake next to the Clinton Park weir. Samples were taken at dawn and dusk for five and one-half consecutive days using a YSI probe (Table 1). All analyses were done in the field; no replicates were preserved for laboratory analysis.

Nitrate-nitrogen and soluble reactive phosphorus were measured for five consecutive days in late October and three consecutive days in early November (Table 1). Only the inflow, W1 outflow, and W2 outflow were sampled. No replicate samples were taken. To treat the samples, an ascorbic acid method was used for phosphate and a cadmium reduction method was used for nitrate. Phosphate and nitrate concentrations of treated samples were measured with a HACH DR/890 colorimeter. Method numbers were the ones for orthophosphate and nitrate-nitrogen that used

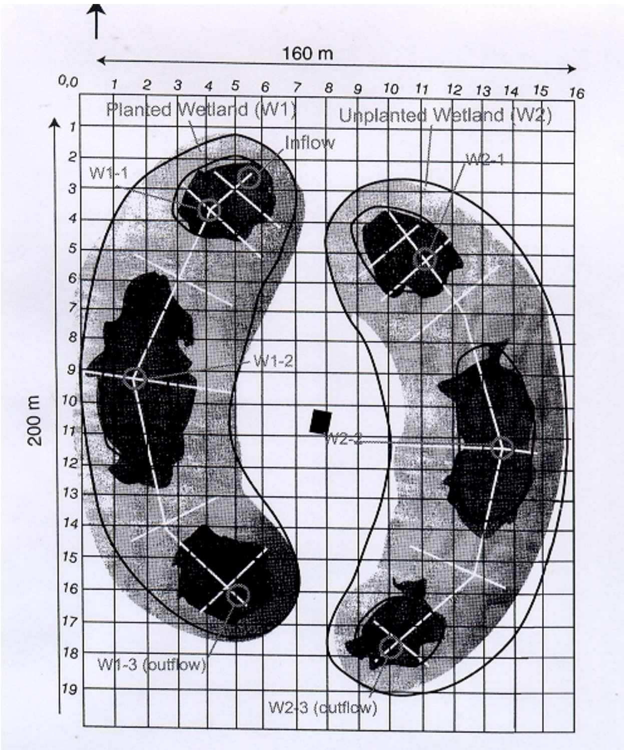

Figure 1: Sampling sites at the Olentangy River Wetland Research Park (ORWRP) experimental wetland basins, October-November 2002

the 10 mL container with no dilution.

Data analysis

Data analysis centered around four main themes: 1) nutrient retention or release in W1 and W2, 2) longitudinal changes in DO, temperature, redox potential, SpC, and pH from inflow to outflow of W1 and W2, 3) comparison of chemical parameters between W1 and W2, and 4) diurnal changes in DO and pH. Nutrient data for each site (inflow, outflow 1, and outflow 2) was averaged and sites were compared using a student T-test. Longitudinal changes were analyzed by looking at the mean DO, temperature, redox, specific conductivity, and pH from the inflow, top, middle, and outflow of each wetland. For each parameter, student T-tests were used to compare the inflow to outflows from W1 and W2. All chemical parameters were analyzed for significant differences between W1 and W2, by comparing values at the top, middle, and outflow of W1 and W2.

Diurnal patterns of DO were analyzed by calculating the absolute rate of change in DO concentrations ([DO2-DO1]/[time2-time1]) between each sampling point (between dawn and dusk or between dusk and dawn, sampling dates and times are in Table 1). The mean rate of change (the average of all these absolute rates of change) was then calculated at the inflow, outflow 1, and outflow 2. A seasonal comparison was made using DO diurnal change data from July 2002, collected with a YSI probe sampling at half-hour frequency. Mean rates of change at the inflow, outflow 1, and outflow 2 were compared between the October and July data sets. Finally, the mean rate of change at the inflow was compared to each outflow in October and July.

The pH data were also plotted to show diurnal change at the inflow, outflow 1, and outflow 2. Mean rates of change were calculated ([pH2-pH1]/[time2-time1]) and compared between the inflow and outflows and between outflows 1 and 2.

All student T-tests for equal means were one-tailed and homoscedastic, and conducted at a 90% confidence interval (a= 0.10). A 90% confidence interval was selected because of the small size of our data set.

Results

Nutrients

Sample size for nitrate-nitrogen and soluble reactive phosphorus was rather small (n=6-8) due to time constraints and the presence of outlier data. Data above 12 mgL^{-1} were dismissed as outliers caused by malfunction of the colorimeter.

The data show an increase in nutrients from the inflow to the outflow in both W1 and W2 (Figure 2). Nitrate concentration increased from 2.32$\pm$0.55 mg NO_3 L^{-1} at the inflow to 4.14$\pm$ 0.94 mg NO_3 L^{-1} at outflow 1 and 4.17$\pm$0.42 mg NO_3 L^{-1} at outflow 2. Using the student T-test, a significant difference in nitrate concentrations was found between the inflow and outflow 1 (p=0.07) and between the inflow and outflow 2 (p=0.01).

Phosphate concentration also increased from 1.40$\pm$0.21 mg PO_4 L^{-1} at the inflow to 2.01$\pm$0.35 mg PO_4 L^{-1} at outflow 1 and 1.85$\pm$0.19 mg PO_4 L^{-1} at outflow 2. A student T-test shows a significant difference in phosphate concentration between the inflow and outflow 1 (p=0.08) and between the inflow and outflow 2 (p=0.07).

Longitudinal data

In general, water quality parameters did not show significant longitudinal variation (Tables 2 and 3). Only

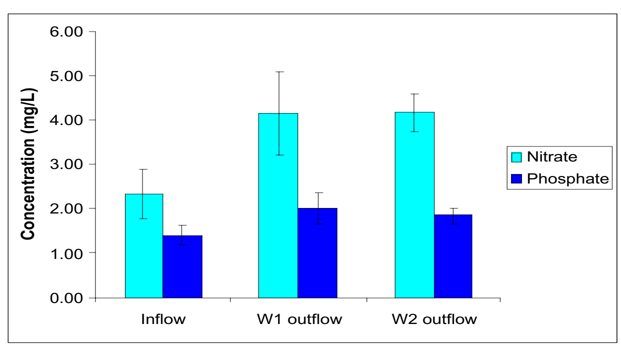

Figure 2: Mean concentration of nitrate and phosphate (mgL^{-1}) in experimental wetland (W1 and W2), October-November 2002.

dissolved oxygen and temperature show a distinct pattern. Both decreased from inflow to outflow in W1 and W2, from 8.40 ± 0.25 mgL^{-1} at the inflow to 6.36 ± 0.79 mgL^{-1} at outflow 1 and 6.40 ± 0.75 mg L^{-1} at outflow 2 (Figure 3). DO concentrations at the inflow were significantly higher than outflow 1 and outflow 2 (p= 0.01 for both). The DO averages presented are an average of dawn and dusk measurements.

Longitudinal changes in temperature were also significant (Figure 4). Temperature decreased from $12.2\pm0.4\,^{\circ}$C at the inflow to $10.4\pm0.6\,^{\circ}$C and $10.6\pm0.7\,^{\circ}$C at the outflows of W1 and W2 respectively. The temperature of the inflow was significantly higher than either outflow (p= 0.01 and p= 0.03, for W1 and W2 respectively). Longitudinal patterns are not apparent for pH, redox potential, or specific conductivity.

Comparison between W1 and W2

There were no significant differences between W1 and W2 for any of the water quality parameters tested (nitrates, reactive phosphorus, temperature, pH, specific conductivity, redox potential and dissolved oxygen).

Table 1. Dates, times, and chemical parameters sampled in experimental wetland, 2002

Date (2002)	Time	DO	SpC	Redox	Temp	pH	NO_3	PO_4
Oct 23	9:00	¸	¸	¸	¸	¸		
Oct 23	18:00	¸	¸	¸	¸	¸		
Oct 24	10:30	¸	¸	¸	¸	¸		
Oct 24	19:00	¸	¸	¸	¸	¸		
Oct 25	8:30		¸	¸	¸	¸		
Oct 25	18:00	¸	¸	¸	¸	¸		
Oct 26	9:30	¸	¸	¸	¸	¸	¸	¸
Oct 26	18:00	¸	¸	¸	¸	¸		
Oct 27*	7:30	¸	¸	¸	¸	¸	¸	¸
Oct 27	17:30	¸	¸	¸	¸	¸		
Oct 28	7:45	¸	¸	¸	¸	¸	¸	¸
Oct 29	16:40						¸	¸
Oct 30	8:05						¸	¸
Nov 8	7:30						¸	¸
Nov 9	8:30						¸	¸
Nov 10	10:15						¸	¸

* Daylight savings time ends. Sunrise and sunset are approximately one hour earlier.

Table 2. Longitudinal data for temperature and dissolved oxygen in W1 and W2, respectively. Numbers are averages of dawn and dusk measurements.

Sampling Site	Temp, °C	D.O. mg/L
River	11.1+0.1 (11)	8.94+0.22 (11)
Inflow	12.2+0.4 (10)	8.40+0.25 (9)
Wetland 1 (top)	10.8+0.5 (11)	8.27+0.06 (9)
Wetland 1 (middle)	10.6+0.7 (11)	6.61+0.46 (10)
Wetland 1 (outflow)	10.4+0.6 (11)	6.36+0.79 (9)
Wetland 2 (top)	10.8+0.5 (11)	8.45+0.29 (9)
Wetland 2 (middle)	10.8+0.6 (11)	7.17+0.46 (9)
Wetland 2 (outflow)	10.6+0.7 (11)	6.40+0.75 (9)

Table 3. Longitudinal data for pH, redox potential, and conductivity.

Sampling Site	pH	Redox, mV	Cond., _S/cm
River	7.93+0.03 (11)	251+16 (11)	599+32 (11)
Inflow	7.79+0.03 (10)	276+20 (10)	594+34 (10)
Wetland 1 (top)	7.80+0.05 (11)	348+11 (10)	605+35 (11)
Wetland 1 (middle)	7.69+0.03 (11)	276+15 (10)	607+32 (11)
Wetland 1 (outflow)	7.82+0.28 (11)	252+22 (11)	567+35 (11)
Wetland 2 (top)	7.83+0.04 (11)	341+20 (10)	606+34 (11)
Wetland 2 (middle)	7.71+0.06 (11)	266+18 (10)	609+33 (11)
Wetland 2 (outflow)	7.70+0.07 (11)	258+19 (10)	615+32 (11)

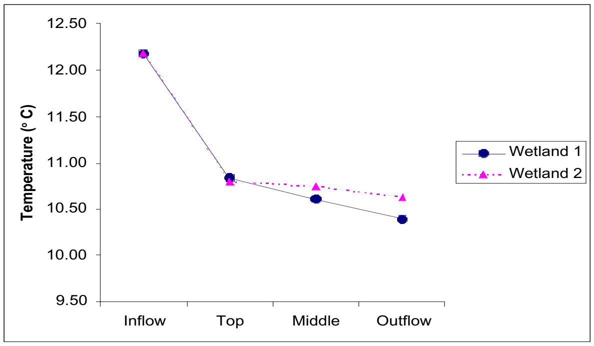

Figure 4. Longitudinal change in temperature in W1 and W2 (° C)

Diurnal patterns of dissolved oxygen

The dawn-dusk measurements of DO concentration show a diurnal pattern, with lower DO readings at dawn and higher DO readings at

dusk (Figure 5). The inflow, outflow 1, and outflow 2 all exhibited the same basic pattern. The weather was cloudy or partly cloudy during the entire sampling period.

October 2002 data were compared to data taken from the same three sites (inflow, outflow 1, and outflow 2) during July 2002. A five and one-half day sampling period was selected from the July data to match the length of the October sampling period. For the inflow and outflow 2 data, this period was from July 8th AM to July 13th AM, 2002. The time period for the outflow 1 data, however, was from July 1st AM to July 6th AM (these are the times during which automated data was available). Data on sunlight in July were not available.

Points were chosen to match the October sampling times. The selected data was plotted in the same manner as the October data (Figure 6)The mean rate of change in DO concentrations was compared between the October and June data (Figure 7). Rates were significantly higher in July compared to October at outflows 1 and 2. At outflow 1, mean rates were 0.92$\pm$0.17 mgL^{-1}hr^{-1} in July and 0.27$\pm$0.10 mgL^{-1}hr^{-1} in October. At outflow 2, mean rates were 0.64$\pm$0.11 mgL^{-1}hr^{-1} in July and 0.18$\pm$0.03 mgL^{-1}hr^{-1} in October. A significant difference was found between July and October data at outflow 1 and outflow 2 (p=0.01 and p=0.00, respectively). At the inflow, mean rates were higher in July (0.15$\pm$0.03 mgL^{-1}hr^{-1} in July and 0.08$\pm$0.04 mgL^{-1}hr^{-1} in October), but the difference was not significant (p=0.11).

Comparing October data from different sites also yields significant results. The rate of change in DO at the inflow is significantly lower than both outflow 1 and outflow 2 (p=0.05 for both). The inflow, therefore, shows significantly less diurnal change than either outflow Similarly, in July, the inflow shows a significantly lower rate of change in DO than outflow 1 and outflow 2 (p=0.00 for both). Inflow and outflow 1 data were taken during two different weeks in July, however, and data on the difference in solar intensity between these weeks is not available.

Diurnal pattern of pH

The pH data also showed a diurnal pattern (Figure 8). The pattern is more dramatic at outflows 1 and 2 than at the inflow. Mean rates of change in pH (units pH/hr) were calculated for each site: 0.01$\pm$0.00 units/hr at the inflow, 0.04$\pm$0.01 units/hr at outflow 1, and 0.03$\pm$0.00 units/hr at outflow 2. Student T-tests indicate that the rates of change in pH are significantly different between the inflow and outflow 1 (p=0.00) and between the inflow and outflow 2 (p= 0.00). The rates of change in pH are not significantly different between outflow 1 and outflow 2 (p=0.27).

Discussion

Nutrient Release

Nutrient results indicate that both W1 and W2 were acting as sources of nitrates and phosphates during late October. This is contrary to most of the academic research on wetlands, in which wetlands have been described as nutrient sinks (Moustafa et al., 1996; Mitsch and Gosselink, 2000; Reddy and D' Angelo, 1997). One possible reason for the discrepancy is seasonal change. During our sampling period, evening temperatures were close to or below freezing and most plants were dead or dying. Less plant growth and productivity means less nutrient demand, and excess nutrients

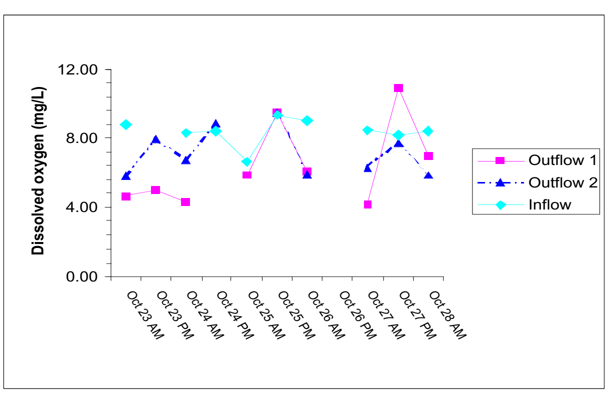

Figure 5. Diurnal pattern of dissolved oxygen in October 2002 (mgL^{-1})

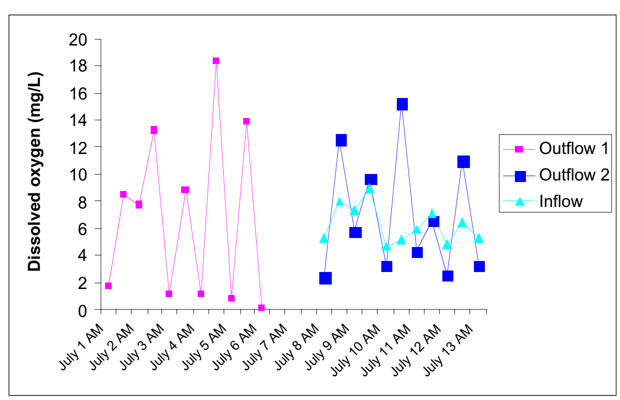

Figure 6. Diurnal pattern of dissolved oxygen in July 2002 (mgL^{-1})

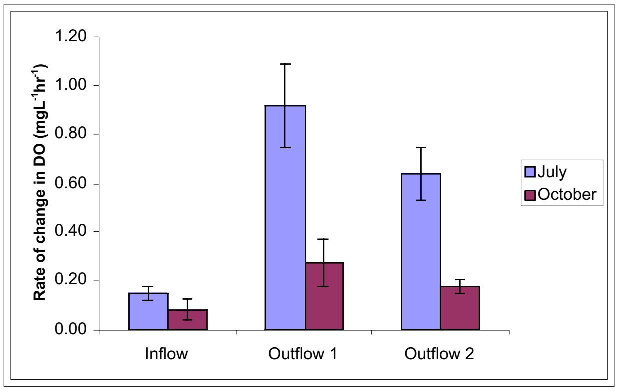

Figure 7. Average rates of change in dissolved oxygen in October and July 2002 ($mgL^{-1}hr^{-1}$)

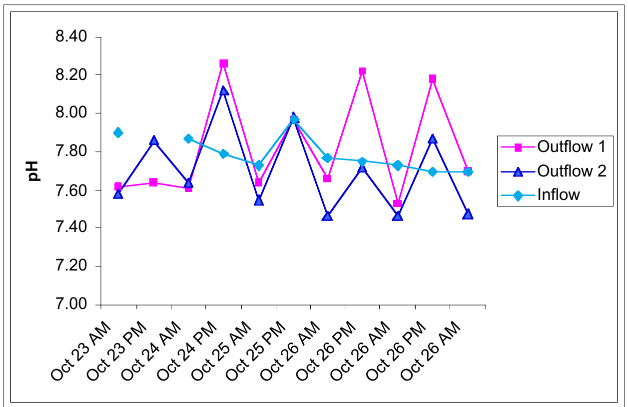

Figure 8. Diurnal pattern of pH in October 2002

probably remained in the water column. The decay of plant matter can contribute additional nutrients to the water column. Finally, decreasing rates of denitrification due to the death of denitrifying bacteria could reduce loss of nitrogen to the atmosphere.

If wetlands consistently act as nutrient sources during cold weather, there could be major implications for the current practice of constructing wetlands as pollutant filters for sewage and urban/agricultural runoff. Though wetlands are excellent sinks for nutrients during the summer and early fall (when plants and microorganisms are actively absorbing them), these nutrients may be released later in the season. Therefore, for at least half of the year, wetlands may be exacerbating the problem of nutrient contamination. This observation was affirmed by Spieles and Mitsch (2000), who noted that "During the winter months in cold-climate treatment wetlands, there is little nitrogen assimilation, a decrease in the release and mineralization of organic nitrogen, and a decrease in the rate of nitrification and denitrification." A better understanding of these seasonal effects is needed to find strategies that work year-round.

Longitudinal patterns

We did not observe any distinguishable longitudinal pattern in pH, conductivity, or redox. However, past studies on the ORWRP have found a decrease in conductivity and redox and an increase in pH from the inflow to the outflows (Mitsch et al., 2000; Nairn and Mitsch, 2000). The decrease in redox is attributed to the anaerobic quality of a wetland compared to a river. The decrease in conductivity and increase in pH are related to higher water column productivity in the wetland compared to the river. Photosynthesis tends to decrease carbonic acids in the water column through consumption of CO_2, making the water both more basic and less conductive (Mitsch et al., 2000).

Since photosynthesis was minimal during our sampling session, we did not see any effect on pH and conductivity. Additionally, our sample size (n=9-11) was probably too small to capture subtle longitudinal changes.

However, we did see a significant decrease in both temperature and dissolved oxygen from the inflow to the outflows. One possible reason for the decrease in temperature is the amount of sunlight that reaches the water. The inflow water comes from the Olentangy River, where the canopy of riparian vegetation does not extend much past the banks. Within the wetlands, however, emergent vegetation provides shade.

The decrease in DO from the inflow to both outflows is particularly interesting since DO generally increases as temperature drops. Other factors must be overwhelming the temperature-dependence. One possibility is decreased water velocity and aeration. Water coming out of the inflow pipe is well aerated by movement and churning inside of the pipe, and further aeration occurs as it spills over the side. Once in the wetland, however, velocity slows and there is less aeration. Additionally, microbial respiration within the water column consumes DO.Throughout most of the year, the tendency to lose DO from inflow to outflow is counter-acted by photosynthesis of submerged macrophytes, which provide a steady flow of oxygen to the water column. In fact, increases in DO from inflow to outflow have been documented in previous studies (Nairn and Mitsch, 2000). During the late fall, however, photosynthesis levels have dropped drastically, and physical factors tend to dominate the system. This seasonal drop in DO production has previously been documented on the ORWRP wetlands (Liptak and Mitsch, 1998).

Differences between W1 and W2

No significant differences were found between W1 and W2. This is in contrast to the 1999 and 2000 studies, which found significant differences between W1 and W2 in six water quality parameters, and the 2001 study that found significant differences in three parameters (Mitsch et al., 2000; Mitsch and Zhang, 2001). One reason for this discrepancy could be that wetland 1 and 2 were really not functionally or structurally different at the time of sampling. Wetland 1 and wetland 2 are identical in every way except for plant species diversity and vegetation type. Because most all of the vegetation was dead or dying at the time measurements were taken, the two wetlands could have been functionally similar; therefore, water quality parameters should not have been significantly different. Our small sample size (n=9-11) compared with the larger sample sizes of earlier studies (n=300-500) is probably another major factor in the discrepancy between our data and that of previous years.

Diurnal Patterns of Dissolved Oxygen

Though all dissolved oxygen measurements were taken on cloudy or partly cloudy days in late October, a diurnal pattern is still visible (Figure 6). Moreover,diurnal changes at the inflow are significantly lower than at each outflow. This difference is generally attributed to greater photosynthetic activity in wetlands compared to rivers, since wetlands tend to support a richer, more diverse community of submerged vegetation. However, it was surprising that the difference was significant in late October, after most wetland vegetation had died.The data from July show a dramatic diurnal pattern with high rates of change in DO (Figure 7). This is due to increased photosynthesis (and consequently, production of DO) in the water column during the summer months, when sunlight is more intense and plants are growing. The July data also show a significantly lower rate of change in DO at the inflow compared to both outflows because of the high density of plants photosynthesizing in the wetlands compared to the river.

The difference in the range of DO concentrations is dramatic. In July, DO reached as high as 18.31 mg/L and sunk as low as 0.15 mg/L, whereas in October DO concentrations reached only 9.43 mg/L and sunk to 4.14 mg/L, hovering at 6-8 mg/L most of the time. There is a need for more research on how these dramatic diurnal changes in DO concentration affect aquatic life such as macroinvertebrates and fish. How do these communities survive the rapid changes in DO concentrations during spring and summer? And how do they then cope with the seasonal change from a rapid rate of change in the spring/summer to a moderate rate of change in the fall/winter? This is just one of the many unique chemical characteristics of wetlands that require special adaptations on the part of wetland biota.

Diurnal Pattern of pH

Similarly to DO, diurnal patterns in pH are caused by photosynthesis. When plants take CO_2 out of the water, they drive the carbonate equilibrium towards CO_2 so that carbonic acid (H_2CO_3 and HCO_3^-) concentrations are reduced. Not only did pH show a diurnal pattern (Figure 8), but also the rate of change was significantly lower at the inflow compared to both outflows. Again, the relative richness of the plant community in the wetlands compared to the river causes diurnal change to be more dramatic. A strong diurnal pattern of pH was surprising this late in the year.

Conclusions

Results indicate that chemical parameters depend highly on seasonal patterns. During the late fall and winter, wetlands tend to produce, rather than absorb, nutrients such as nitrate and phosphate. Also in the fall/winter, wetlands tend to consume more dissolved oxygen than they produce, since microbial respiration is still active while plant photosynthesis is lessened. In the summer and early fall (during the growing season), wetlands can be a sink for nutrients and a source of dissolved oxygen.

It is important to understand how seasonal patterns affect wetland chemistry, particularly since wetlands are commonly being used to mitigate water pollution and improve water quality. A wetland is anything but a static ecological system: it changes its chemical properties yearly, monthly, daily, and even hourly. These changes must be understood in order to make intelligent and viable management decisions about wetland mitigation.

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